Processing of COBRA FMCW SAR Data

Frioud, Max ; Wahlen, A ; Essen, H ; Meier, Erich

Abstract: We present results from air-borne SAR campaigns using the FMCW SAR system COBRA operating at 35 GHz. Thanks to its large bandwidth the theoretical image resolution is below 10 cm in both the range and azimuth dimensions. Highly precise navigation data as well as very accurate synchronization of navigation and SAR data enables equally accurate absolute positioning. The SAR data were focused using a Frequency Scaling Algorithm (FSA) that accounts for the movement of the platform during the long ramp duration. The focusing chain integrates a two-step motion compensation scheme. The geometric and radiometric characteristics of the resulting single look complex (SLC) images were analyzed based on corner reflectors deployed within the test site. The scene was illuminated several times from two opposite directions in a standard strip-map mode. For each track, highly overlapping data segments were focused and geocoded individually. These products were subsequently mosaicked to generate a single geocoded image. Examples of change detection and moving target indication are also given.

Originally published at:
Frioud, Max; Wahlen, A; Essen, H; Meier, Erich (2012). Processing of COBRA FMCW SAR Data. In: PIERS 2012, Kuala Lumpur, 27 March 2012 - 30 March 2012. Electromagnetics Academy, 322-327.

Processing of COBRA FMCW SAR Data

M. Frioud[1], **A. Wahlen**[2], **H. Essen**[2], **and E. Meier**[1]

[1]Remote Sensing Laboratories, University of Zurich, Zurich, Switzerland
[2]Fraunhofer FHR, Wachtberg, Germany

Abstract— We present results from air-borne SAR campaigns using the FMCW SAR system COBRA operating at 35 GHz. Thanks to its large bandwidth the theoretical image resolution is below 10 cm in both the range and azimuth dimensions. Highly precise navigation data as well as very accurate synchronization of navigation and SAR data enables equally accurate absolute positioning. The SAR data were focused using a Frequency Scaling Algorithm (FSA) that accounts for the movement of the platform during the long ramp duration. The focusing chain integrates a two-step motion compensation scheme. The geometric and radiometric characteristics of the resulting single look complex (SLC) images were analyzed based on corner reflectors deployed within the test site. The scene was illuminated several times from two opposite directions in a standard strip-map mode. For each track, highly overlapping data segments were focused and geocoded individually. These products were subsequently mosaicked to generate a single geocoded image. Examples of change detection and moving target indication are also given.

1. INTRODUCTION

As reported in [1] and [2], the COBRA system is a modular FMCW SAR system with four front-end modules at 10 GHz, 35 GHz, 94 GHz and 220 GHz, coupled to a common data-acquisition unit. It was originally developed for high resolution imaging in ground-based applications, such as ISAR in a tower/turntable configuration or in a ground based SAR mode (rail-SAR).

In [3] and [4] results of COBRA operating in a standard air-borne strip-map SAR mode were reported. In [3] the data was used to exemplify a novel processing scheme in the wave-number domain while it was processed in the time domain in [4]. In [4] the focusing quality was assessed by looking at the signature of some strong scatterers.

In this paper we present the results obtained from two 35 GHz measurement campaigns that took place in May 2010 and May 2011 over a rural area in Switzerland. Nine and respectively fourteen linear tracks were flown over the same area. For both campaigns, the focusing quality as well as the geometric accuracy could be properly assessed thanks to the deployment of several corner reflectors in the scene. In 2010 the system was operated in two different modes corresponding to different chirp-rates as well as different nominal flight altitudes, while a single mode was used in 2011.

2. THE COBRA FMCW SAR SYSTEM

The COBRA system is well described in [2]. As a side-effect of its modular architecture sharing the same data-acquisition system as the pulsed-radar MEMPHIS[1], a full duty-cycle cannot be achieved. Although the data share the characteristics of a continuous wave system due to the extreme long pulses and the dechirp-on-receive technique used in the acquisition chain, the system is still a pulsed one, in the sense that no signal is transmitted between two consecutive ramps. The nominal measurement parameters used during the reported campaigns are shown in Table 1.

COBRA is carried by a Transall C-60. The navigation data are based on three units, namely the onboard INS/GPS units as well as a 20 Hz dGPS system. The synchronization between the navigation and the SAR data was considerably enhanced using a direct link and event markers.

3. PROCESSING METHOD

As is usually the case for FMCW SAR systems, the received data was de-ramped by mixing with the transmitted signal and this de-ramped data was subsequently demodulated to base-band. The

[1]The experimental pulsed radar system MEMPHIS is described in [3].

demodulation brings the center of the range frequency interval of interest to zero. The frequency scale is directly associated with the slant range scale, while the mid-range is given by

$$R_m = \frac{c \cdot F_0 \cdot T_0}{2 \cdot B_w} \tag{1}$$

where F_0 is the demodulation frequency, T_0 is the nominal ramp duration, B_w is the nominal bandwidth and c is the speed of light. The mid-ranges corresponding to the nominal ramp durations in Table 1 are approximately 453 m and 798 m respectively. The corresponding maximum unambiguous ranges are half these values.

A FMCW Frequency Scaling Algorithm (FSA) as described in [6] was chosen to focus the data. This algorithm compensates very accurately the dilation in the received signal caused by the relative motion between radar and target during reception and between transmission and reception, while avoiding any interpolation. A two-step motion compensation scheme is integrated within this processing chain as described in [7]. The first step is a bulk correction performed prior to starting FSA while the second step is a differential correction performed in the time domain before the azimuth match filtering.

Highly overlapping data segments were focused with FSA and geocoded using a 2 m resolution lidar terrain model as reference height. The pixel size of the geocoded images is 10 cm. The resulting geocoded products were mosaicked to generate a single geo-referenced image.

Table 1: Nominal measurement parameters of the COBRA system.

Carrier frequency	35.2 GHz
Azimuth antenna beamwidth	3.3°
Pulse repetition frequency	1600 Hz
System bandwidth	2 GHz
Sampling frequency	25 MHz
Demodulation frequency	50 MHz
Ramp duration	121 µs or 213 µs
Flying altitude	180 m or 330 m
Mean velocity	79 m/s
Look direction	left
Depression angle	23.5°

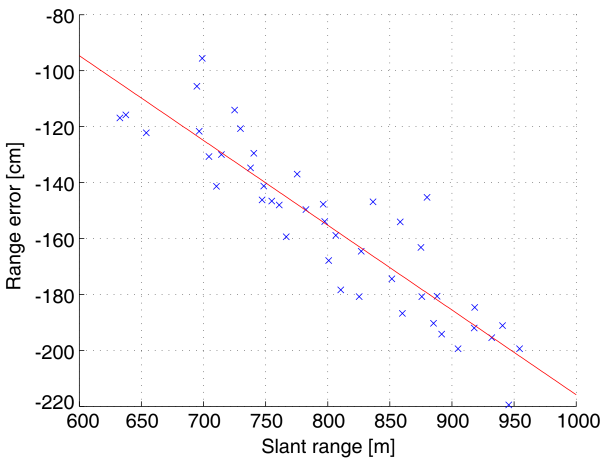

Figure 1: Distribution of the absolute errors in range versus slant range for all matches of the 14 data takes and 4 reflectors (44 cases) before calibration (see text).

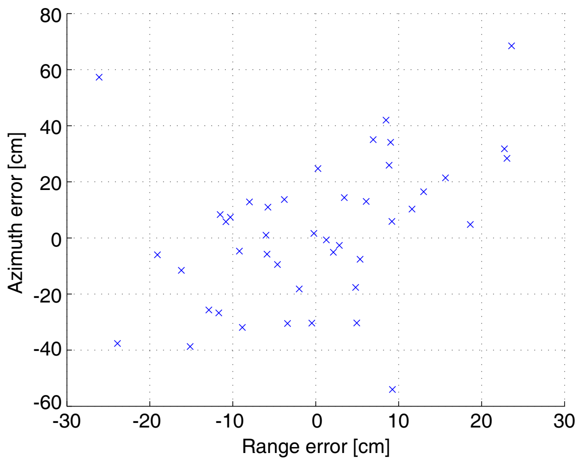

Figure 2: Distribution of the absolute errors for all matches of the 14 data takes and 4 reflectors (44 cases) after calibration (see text).

4. RESULTS

4.1. Absolute Positioning

The position of the reflectors deployed in the scene was measured with a precision of a few centimeters. To check the absolute positioning the data were focused around positions of the reflector. For every possible match of the tracks with the reflectors, a point target analysis was performed. The absolute accuracy depends on the state vector of the antenna phase center which virtually follows a linear track at constant velocity after the motion compensation.

Figure 1 presents the errors obtained in the range direction as a function of slant range for the four reflectors for all of the 2011 data takes, when using the nominal system parameters listed in Table 1. We can observe large systematic errors in range (average of −156.1 cm) as well as a significant linear trend of this error as a function of the slant range, leading to a standard deviation of 29.7 cm. Unlike the errors in the range direction, the errors in azimuth are almost independent on the slant range and average out to only 2.1 cm (standard deviation of 27.1 cm). Although an uncertainty in the lever arm could contribute efficiently to the systematic error in range, the most likely source of error is the uncertainties in the actual sampling and demodulation frequencies. In absence of independent estimates of these uncertainties, these values have been calibrated so as to cancel out the average range error as well as its slant range dependency. The resulting error distribution is shown in Figure 2. After calibration the standard deviations of the range and azimuth errors are 12.0 cm and 26.0 cm respectively.

The absolute positioning accuracy was also assessed by comparing the geocoded products with an orthophoto. Figure 3 presents an example of a mosaicked image from the data take 1 in 2011, where the geocoding process used a lidar terrain model. The SAR image geometry is seen to be very consistent with the orthophoto product from the Swiss Federal Office of Topography. The nominal standard deviation of the geolocation of this product is 25 cm.

4.2. Focusing Quality

From the parameters in Table 1, theoretical resolutions of about 7.5 cm in both range and azimuth are expected. One needs to bear in mind that the pixel spacings in range and azimuth are about 8 cm and 5 cm respectively. Figure 4 presents an example of point target analysis for a reflector

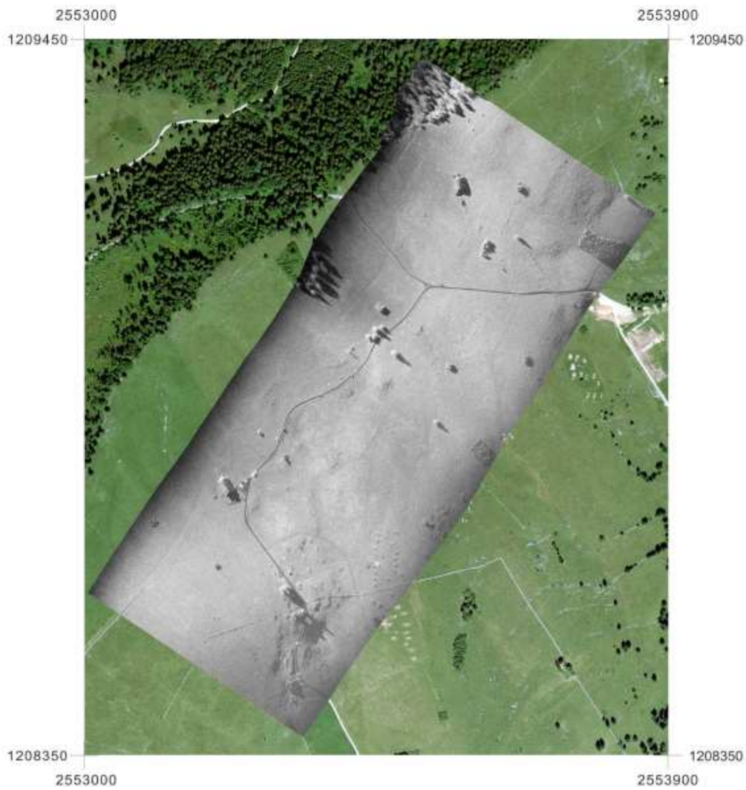

Figure 3: Mosaicked image from the data take 1 in 2011. The SAR image is superimposed over an orthophoto. The coordinate system is LV 95.

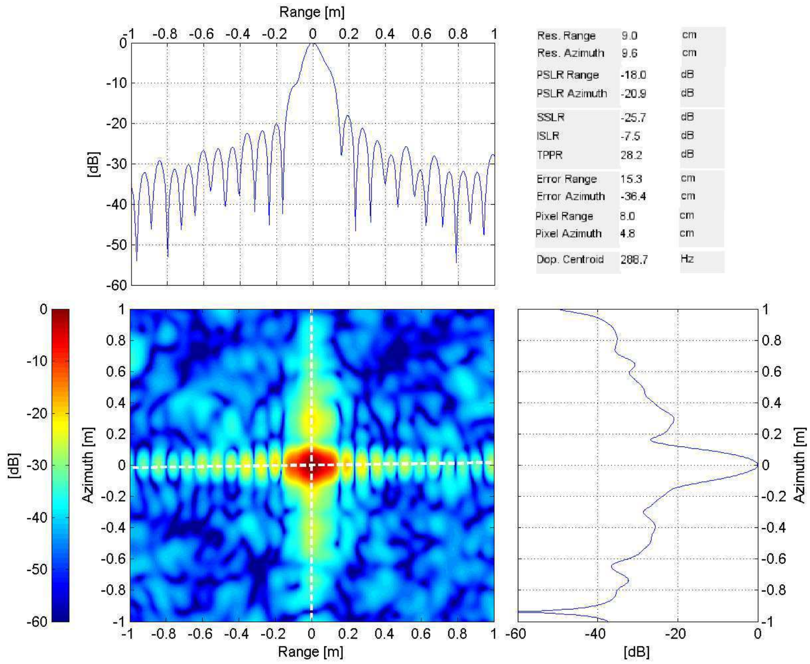

Figure 4: Example of point target analysis (data take 7 in 2010). The 2D plot presents the intensity distribution of the detected image 2 m × 2 m around the detected peak. The top and right panels present the corresponding sections along range and azimuth. The corresponding geometric and radiometric characteristics are listed.

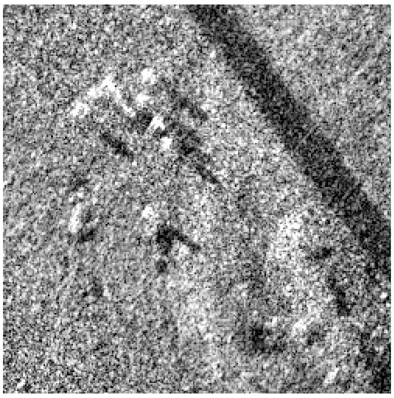

Figure 5: Zoomed view of a geocoded product from the data take 1 in 2011.

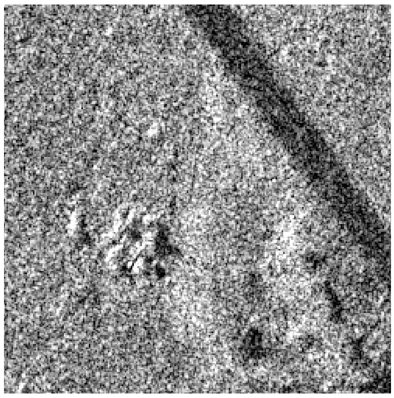

Figure 6: Zoomed view of a geocoded product from the data take 3 in 2011.

located almost at mid-range of the data take 7 in 2010. We observe that the radiometric values obtained are close to the theoretical expectation.

4.3. Change Detection

The Figures 5 and 6 present the same zoomed area 25 m × 25 m in size from two different data takes in 2011, showing a group of people in two different configurations. The length of the shadows indicate that most of the people in Figure 5 are standing, while they're seated in Figure 6. Note that thanks to the small azimuth beamwidth, the aperture time is only about 0.35 s. As a consequence, the de-focusing due to possible movements of the people is relatively small.

4.4. Moving Target Indication

In 2011 a convoy of 4 vehicles was driving through the test site. Figure 7 shows an extract around the observed signatures in the geocoded image from the data take 1. The area is 180 m × 180 m in size. The aircraft is heading towards the SW while the vehicles are heading almost in the opposite direction. The shadows of the four vehicles are located to the SE of their actual position, while the signatures of the vehicles are seen to be notably shifted in azimuth.

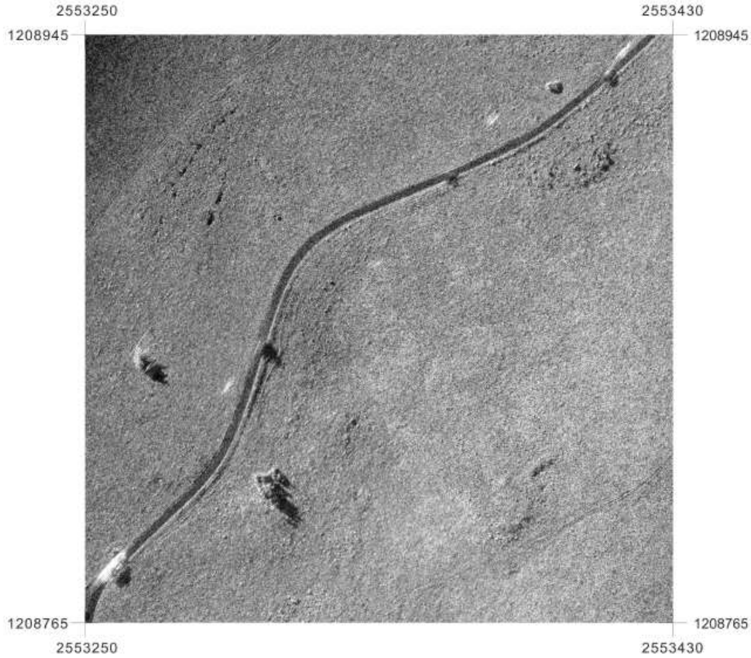

Figure 7: Zoomed view of a geocoded product from the data take 1 in 2011, where the signatures of four moving vehicles are visible. The coordinate system is LV 95.

5. CONCLUSION

This paper describes the COBRA FMCW millimetre-wave SAR system during two campaigns in May 2010 and 2011 over a rural area of Switzerland while it was operating in low-altitude strip-map mode. The data was focused using a frequency scaling algorithm that accounts for the platform movement during the long ramp duration. The geometric accuracy as well as the focusing quality was assessed by a point target analysis using corner reflectors. Resolutions below 10 cm as well as peak sidelobe ratios below −18 dB were achieved while the distribution of the positioning errors are characterized by standard deviations of about 12 cm and 26 cm in range and azimuth, respectively. Potential applications such as change detection and moving target indications were demonstrated.

ACKNOWLEDGMENT

This work was funded by ARMASUISSE. We are very grateful to all the collaborators of the involved institutions for their contributions during the measurement campaigns.

REFERENCES

1. Essen, H., et al., "Very high bandwidth millimetre-wave radar," *Electronic Letters '08*, Vol. 41, No. 22, 1247–1249, 2005.
2. Essen, H., et al., "High resolution millimetre wave measurement radars for ground based SAR ansd ISAR imaging," *Proceedings of the Radar Conference '08*, 1247–1249, Rome, Italy, May 2008.
3. Wang, R., et al., "Focus FMCW SAR data using the wavenumber domain algorithm," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 48, No. 4, 2109–2118, 2010.
4. Ribalta, A., et al., "High resolution FMCW-SAR image generation," *Proceedings of the 8th European Conference on SAR*, 1–4, Aachen, Germany, Jun. 2010.
5. Schimpf, H., et al., "MEMPHIS — A fully polarimetric experimental radar," *Proceedings of the International Geoscience and Remote Sensing Symposium*, Vol. 3, 1714–1716, Toronto, Canada, Jun. 2002.
6. Zhihong, J., et al., "Modified frequency scaling algorithm for FMCW SAR data processing," *Chinese Journal of Aeronautics*, Vol. 20, 339–345, 2007.
7. Zaugg, E. C. and D. G. Long, "Theory and application of motion compensation for LFM-CW SAR," *IEEE Transactions on Geoscience and Remote Sensing Symposium*, Vol. 46, No. 10, 2990–2998, 2008.